Electrical Resistance of Ceramic Matrix Composites for Damage Detection and Life-Prediction

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Abstract

The electric resistance of woven SiC fiber reinforced SiC matrix composites were measured under tensile loading conditions. The results show that the electrical resistance is closely related to damage and that real-time information about the damage state can be obtained through monitoring of the resistance. Such self-sensing capability provides the possibility of on-board/in-situ damage detection or inspection of a component during "down time". The correlation of damage with appropriate failure mechanism can then be applied to accurate life prediction for high-temperature ceramic matrix composites.

Procedure
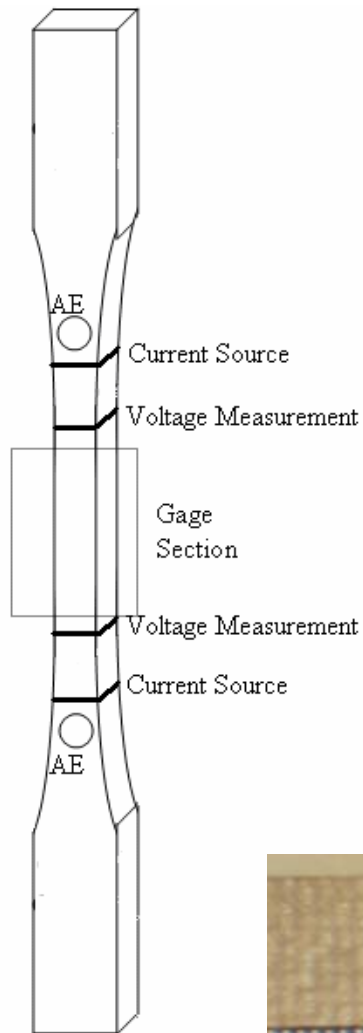
- 150mm specimens with contoured gage section

- Loaded, unloaded, and reloaded in tension on an Instron Universal Testing Machine

- Loaded at rate of 4kN/min

- Capacitance strain gage used with 1% range over 25mm (metal knife-edge contact extensometers were tried, but abandoned because of electrical interference)

- Resistance measured by four- point probe method using an Agilent 34420 micro-Ohm meter

- Conductive silver paste was used to improve contact between specimen and voltmeter

- Acoustic emission monitored by 50kHz to 2MHz sensors just outside the gage section
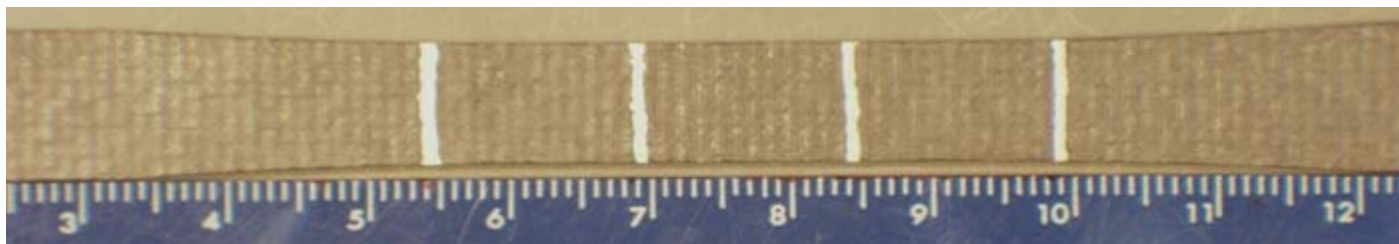
Resistivity Comparison

Comparison of Matrix Types

Comparison of Fiber Types
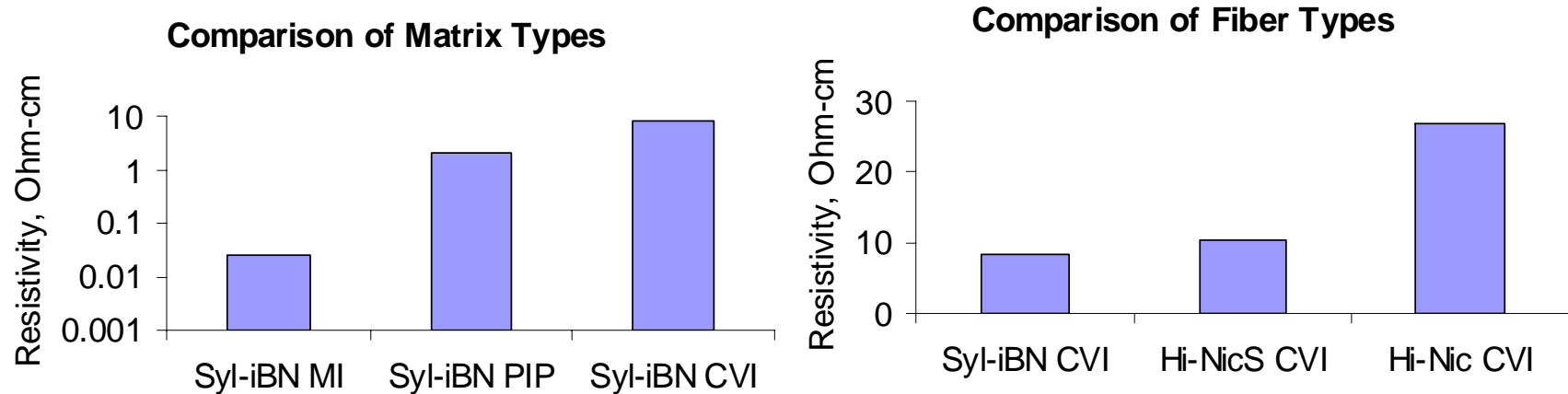
Of the three matrix types examined, MI was the least resistive while CVI was the most resistive. This seems logical, since the MI matrix consists of a continuous layer of more conductive Si, whereas CVI matrix is solely SiC. Also, the Syl-iBN fibers were the least resistive, while the Hi-Nic fibers were approximately three times as resistive as the other fibers. These results are consistent with the fiber types: The Hi-Nic fibers are lower temperature processed fibers containing nanocrystalline SiC particles and amorphous particles, while the Syl-iBN and Hi-NicS fiber types are both polycrystalline SiC fibers processed at higher temperatures.

	Manufacturer	Fiber	Mat.	Ends per Inch	# of Plys	Fiber Radius, mm	Fibers per Tow	Thick-ness, mm	Fiber Vol. Fract.	E, GPa	Nominal Resistivity (ohm-cm)
Syl-iBN MI	GEPSC; Newark, DE	Syl-iBN*	MI	20	8	0.005	800	2.01	0.394	230	0.02
Syl-iBN PIP	COIC; San Diego, CA	Syl-iBN*	PIP	20	10	0.005	800	2.11	0.469	160	2.15
Syl-iBN CVI	Hyper-Therm; Huntington Beach, CA	Syl-iBN*	CVI	20	8	0.005	800	2.55	0.310	205	10.36
Hi-Nic S CVI	Hyper-Therm	Hi-Nic-S**	CVI	18	8	0.0065	500	3.05	0.247	252	10.45
Hi-Nic CVI	Hyper-Therm	Hi-Nic**	CVI	17	8	0.00675	500	3.79	0.202	235	27.00

All composites have a BN interphase
* COIC Sylramic + NASA iBN heat treatment; **Nippon Carbon, Tokyo, Japan

Results

The following figures are plots of the applied stress, acoustic energy, and resistance change of the samples as they were tensile tested in hysteresis loops. For each stress loop, the resistance increases at first and then reduces, in response to the stress change in the loop. It is interesting that all specimens are characterized by a resistance curve that closely follows the slope of the acoustic curve for the first few loading cycles and then increases at a greater rate than AE at higher stresses. This characteristic indicates that the first portion of the resistance curve is caused by matrix crack formation, while the higher stress portion is a result of phenomenon that do not cause acoustic emission, such as crack opening and fiber strain. All samples are well behaved in the sense that the resistivity curve for the unloading of one cycle and loading of the subsequent cycle is symmetric. In other words, as the specimen is reloaded, resistivity returns to the previous maximum and then increases at a greater rate once acoustic events commence. Matrix cracks that are closed or partially closed upon unloading are reopened as stress increases, followed by the formation of new cracks once the stress level exceeds the previous maximum. This repeatable pattern indicates that the number and severity of matrix cracks, along with accurate estimates of remaining life, can be determined at any point in the service life of a part.
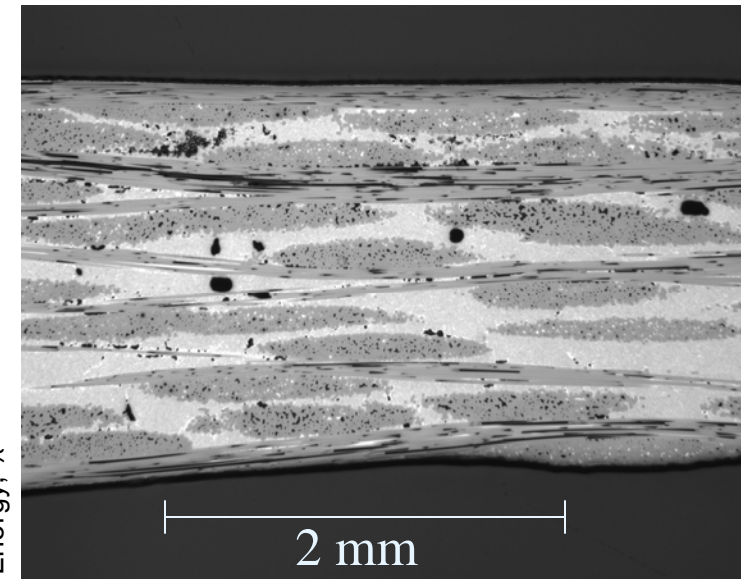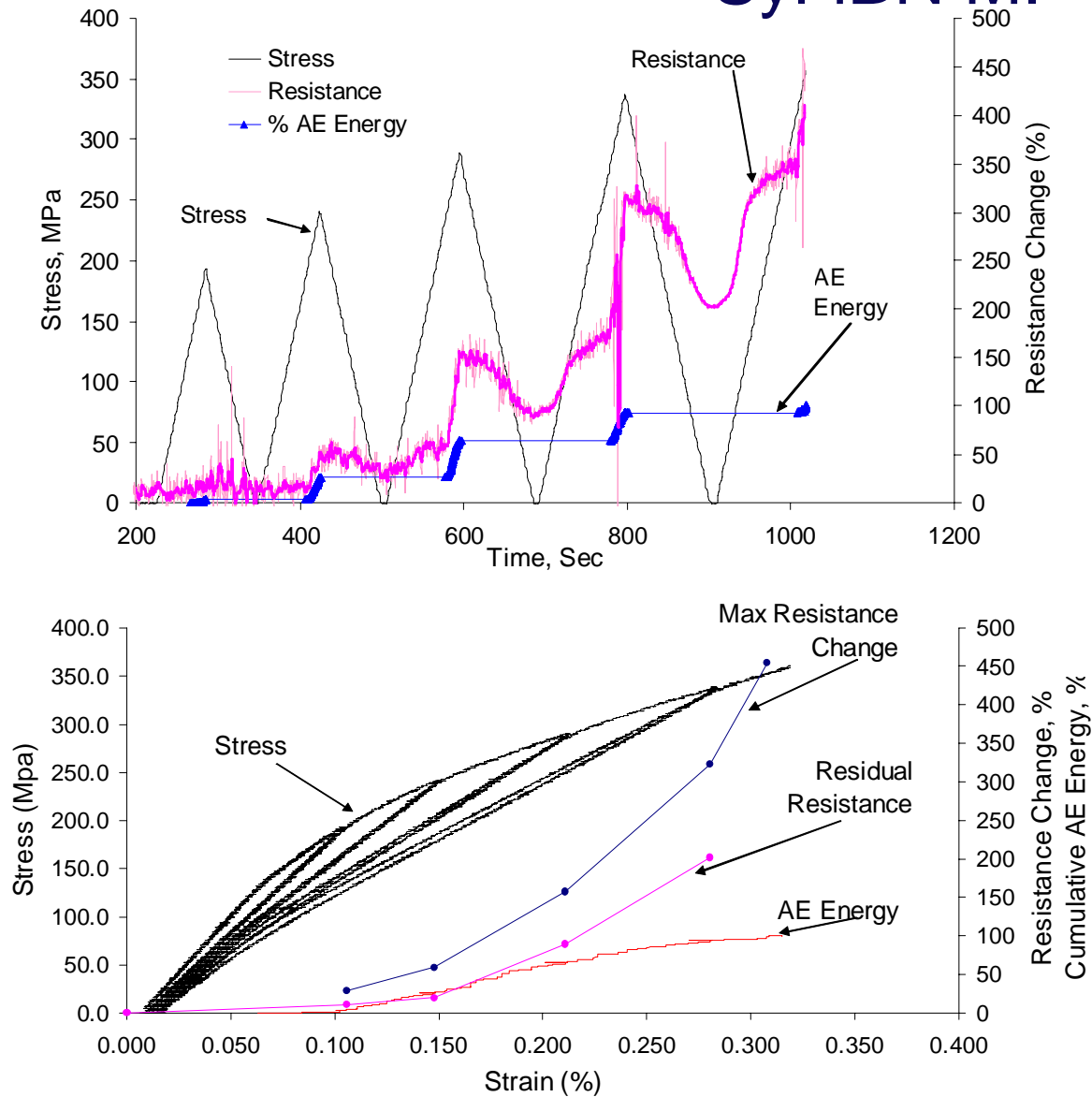
Results

Another interesting characteristic of the resistance curves is the residual resistance. Upon unloading, resistivity drops below the peak value, but never fully returns to the level it was at prior to loading. There is permanent change in resistivity upon each loading cycle. The graphs for each sample show the maximum and residual resistance change in each loop as a function of stress. Both maximum and residual resistances increase with increasing stress. The value of the residual resistance depends on the maximum stress during past loading loops. Obviously, the irreversible resistance is attributed to the matrix cracks that are formed during the loading cycle. This behavior indicates that the damage and maximum loading history could be "recorded" by the residual resistance. Such features could be valuable for a host of other loading and damage conditions. For instance, after a mission is complete and the structure is unloaded, the damage contribution to the resistance remains. The measured response is thus that of the largest stress experienced by the component in the vicinity of the measurement. Hence, the residual resistance change relates to inspection applications.
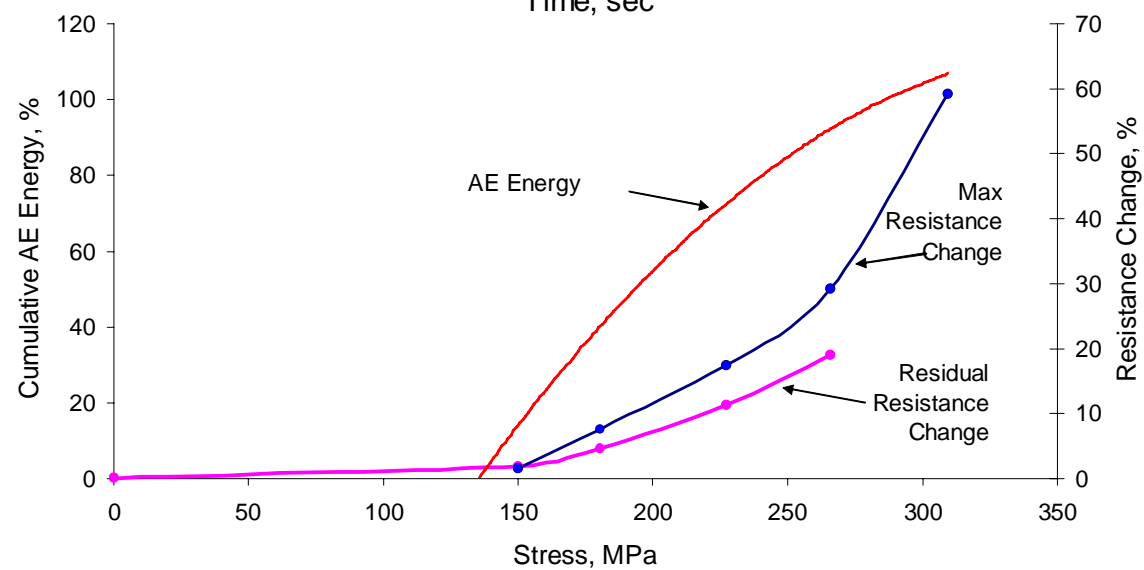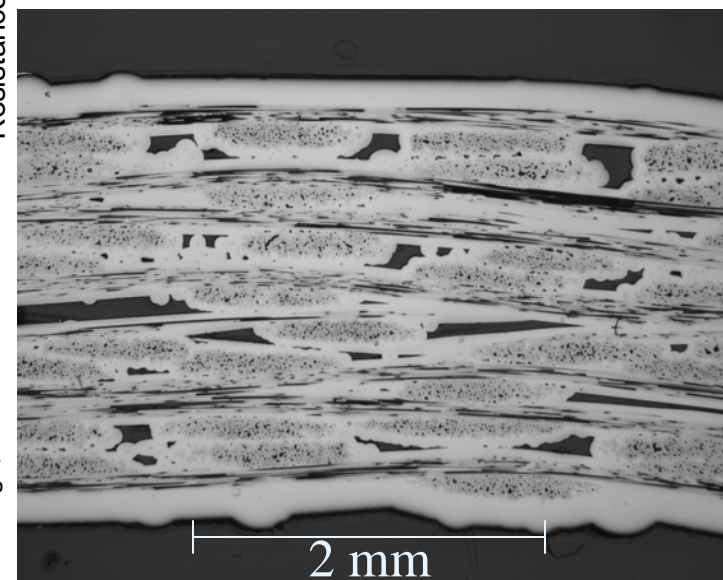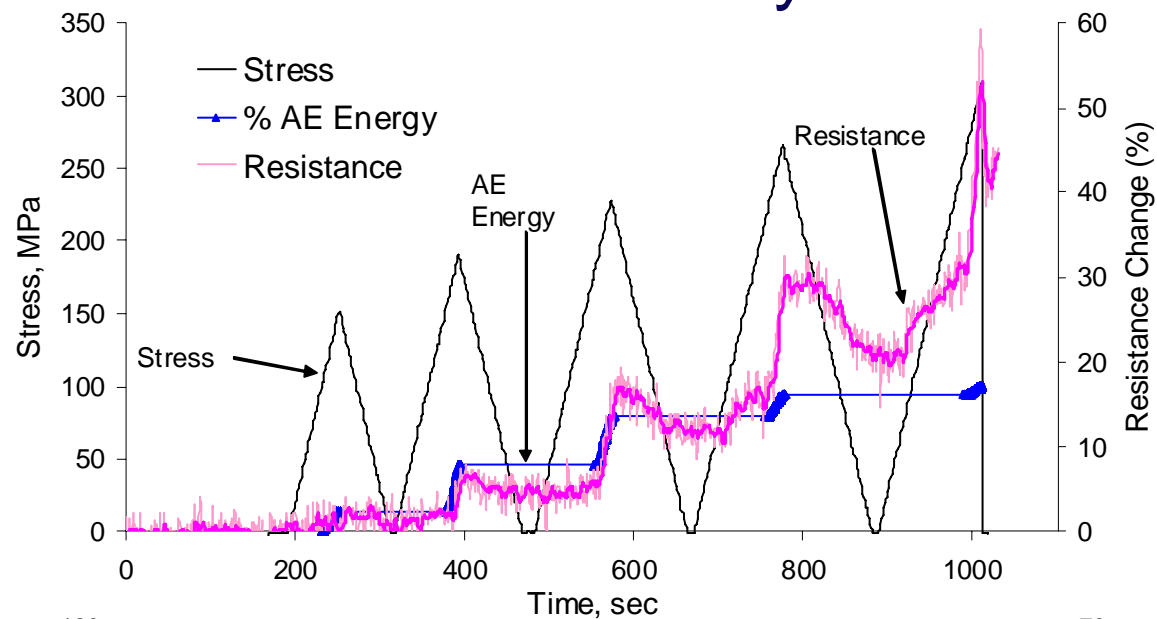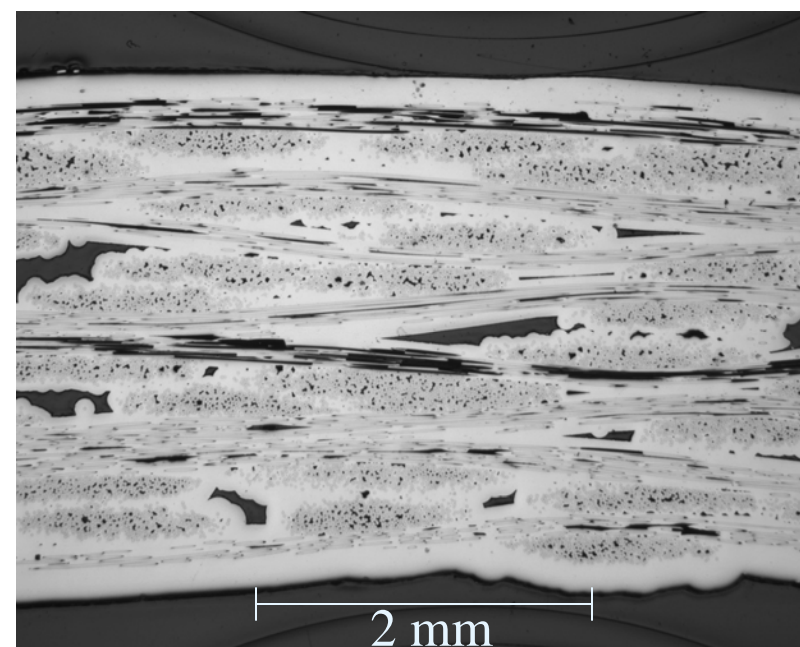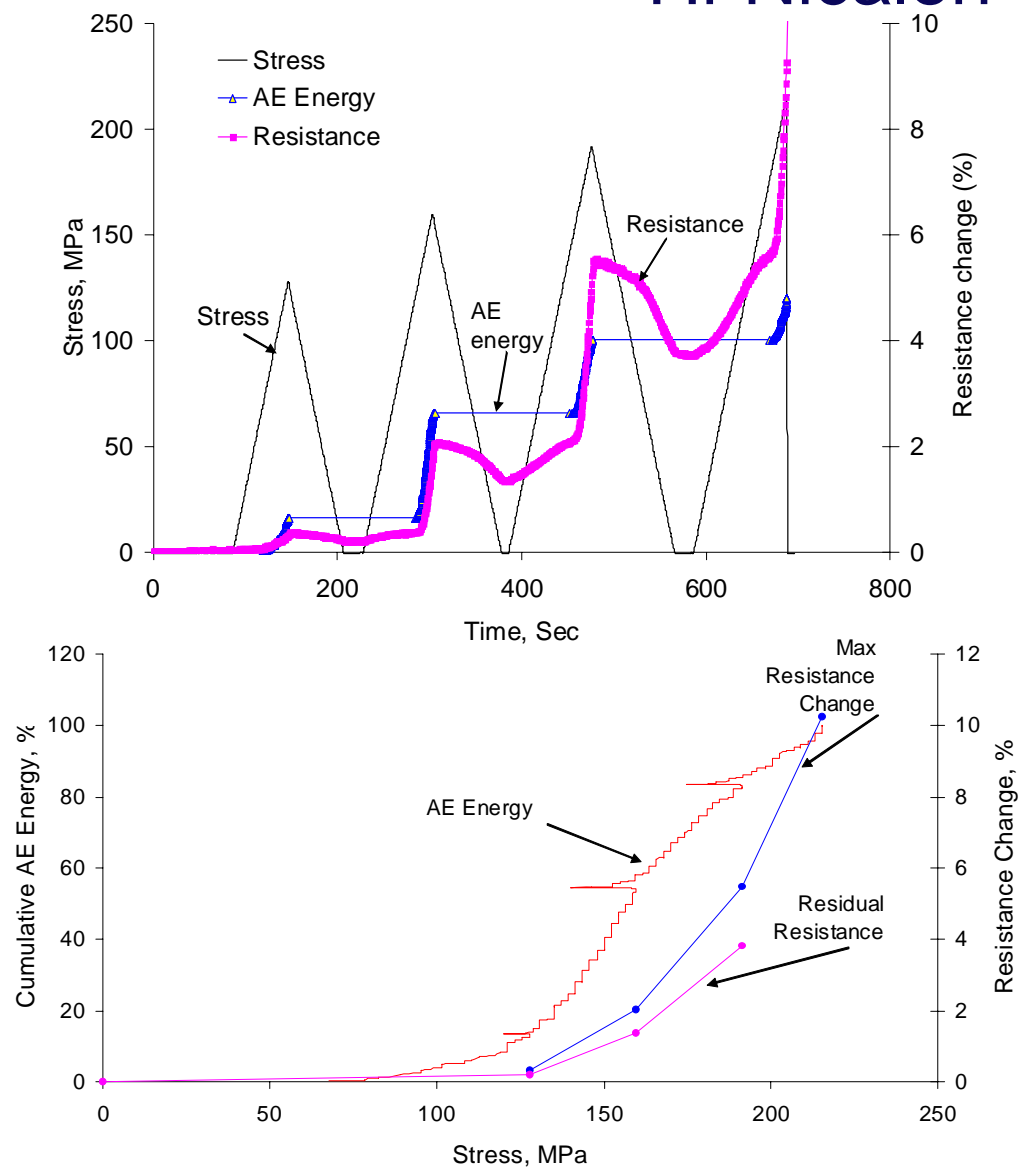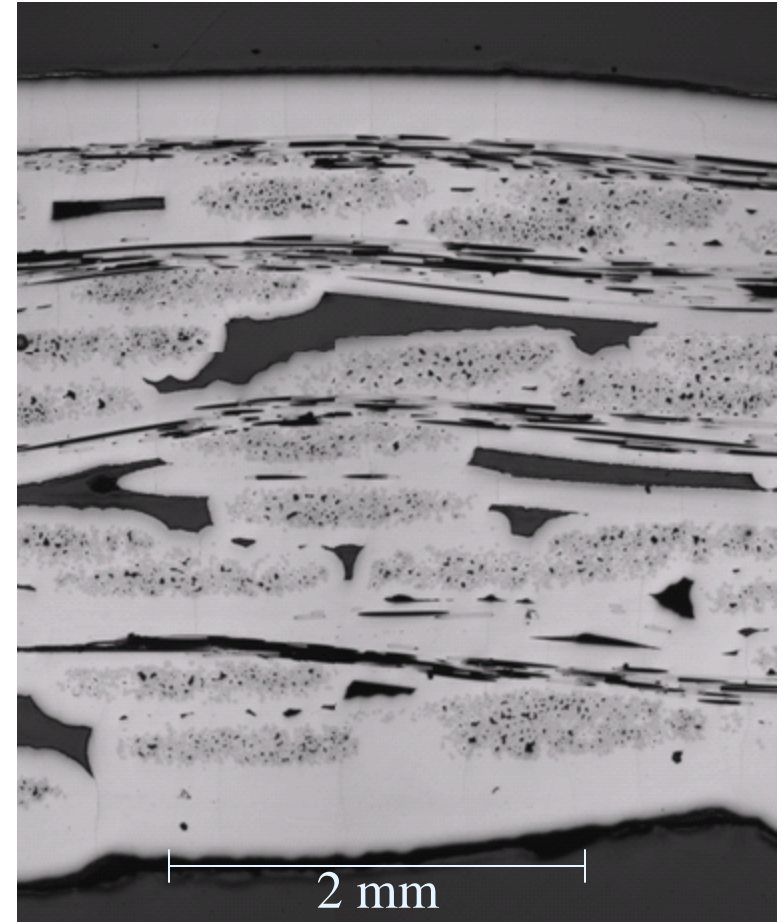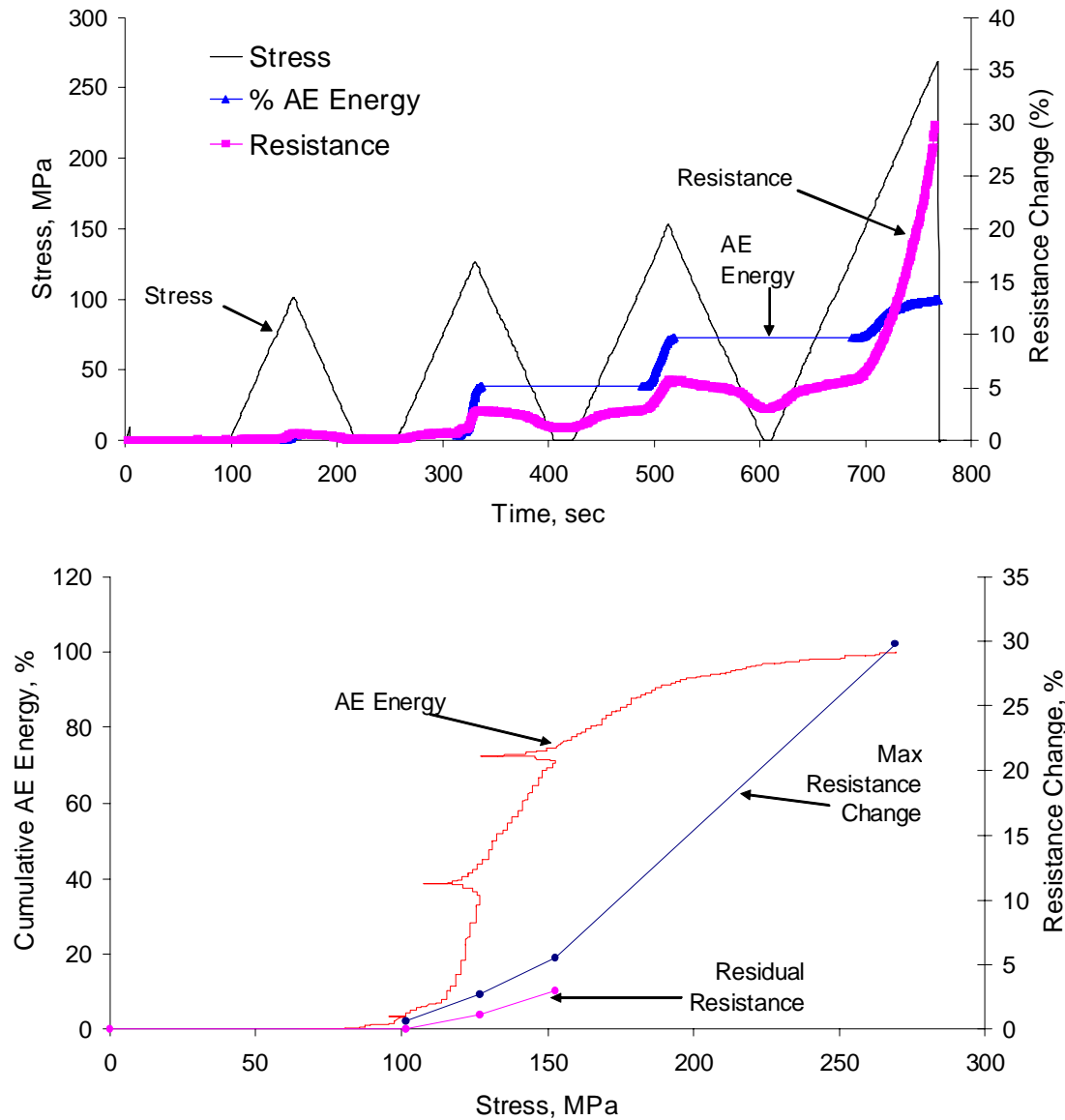
Syl-iBN MI

Syl-iBN CVI

Hi-Nicalon S CVI

Hi-Nicalon CVI

Summary and Conclusions

- Results presented here demonstrate that self-sensing using conductivity can effectively detect matrix damage, which is critical to the implementation of SiC/SiC in high- temperature structural applications

- We have shown that residual resistance can be correlated with damage, thus allowing for observation of structural integrity

- These results provide a basis for developing a non-destructive evaluation method for high temperature CMC materials

Future Work

- Measure resistivity of individual fibers under loading conditions to determine stress-dependence of resistivity for fibers and fiber contribution to overall resistivity with stress

- Examine microstructures of samples that were interrupted and tested to failure to get a better correlation between resistivity change and the number and length of matrix cracks

- Determine resistivity during elevated temperature testing

- Develop multi-scale model for predicting the damage evolution

Acknowledgements

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